WSRC-MS-2001-00592

High Level Waste, High Bay Exhaust Fans
Analyzing a Beat Frequency (U)

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Prepared for the U.S. Department of Energy under Contract No. DE-AC09-96SR18500

This document was prepared in conjunction with work accomplished under Contract No. DE-AC09-96SR18500 with the U.S. Department of Energy.

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KEYWORDS:
High Level Waste
Savannah River Site
Predictive Maintenance
NWTF High Bay
Vibration Analysis
Beat Frequency

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Abstract

Vibration analysis has improved plant safety and reliability at the Westinghouse Savannah River Company (WSRC) through early detection of equipment problems. Vibration analysis detects repetitive motion of a surface on rotating or oscillating plant equipment. Either unbalance or the impacting of moving parts with surface defects causes this repetitive motion. The motion is proportional to the size and location of the impacts or to the magnitude of the unbalance in the equipment.

The various vibration frequencies in rotating equipment can be related to the geometry and to equipment operating speed. By knowing the relationship between frequencies and types of defects with which they are linked, a vibration analyst can determine the nature and seriousness of vibration problems.

One vibration problem that can be detected using vibration analysis is a "beat frequency". James E. Berry of Technical Associates of Charlotte, Inc., defined a beat frequency as two closely spaced frequencies going into and out of synchronization with one another. More often than not "beat vibration" occurs when two or more steady-state vibration sources generate frequencies in close proximity to one another.[1]

Plant equipment at WSRC was designed to operate without beat frequencies. Like other plants, WSRC goes through many plant reconfigurations to remain competitive and to help improve plant processes. These changes along with the repairs done to the equipment by various maintenance departments around the site opens the door for a beat frequency problem to occur.

Problem Summary

The High Level Waste (HLW) Predictive Maintenance group was asked to help trouble-shoot high vibration levels on two centrifugal fans. These fans where designed to provide ventilation for the staging area called High Bay in the HLW New Waste Transfer Facility. Both fans are overhung, belt driven and are spring mounted on individual steel frames, which is isolated from the concrete floor.

During data collection the analyst noticed that the 1x RPM peak was pulsating. Further examination of the vibration data, using zoom analysis, revealed that this peak was actually two peaks closely spaced together creating a beat frequency. The wide-band spectrum normally used during routine vibration analysis was showing only one peak.

Wide-band Spectral Test Data

Wide-band spectral data was collected during the test with a Computational Systems Incorporated (CSI) multi-channel machinery analyzer. The CSI multi-channel analyzer computed a Fast Fourier Transform (FFT) or Discrete Fourier Transform (DFT) spectrum by performing spectrum averaging on each measurement point on the High Bay fans (See Figure 1).[2]

Spectrum Averaging

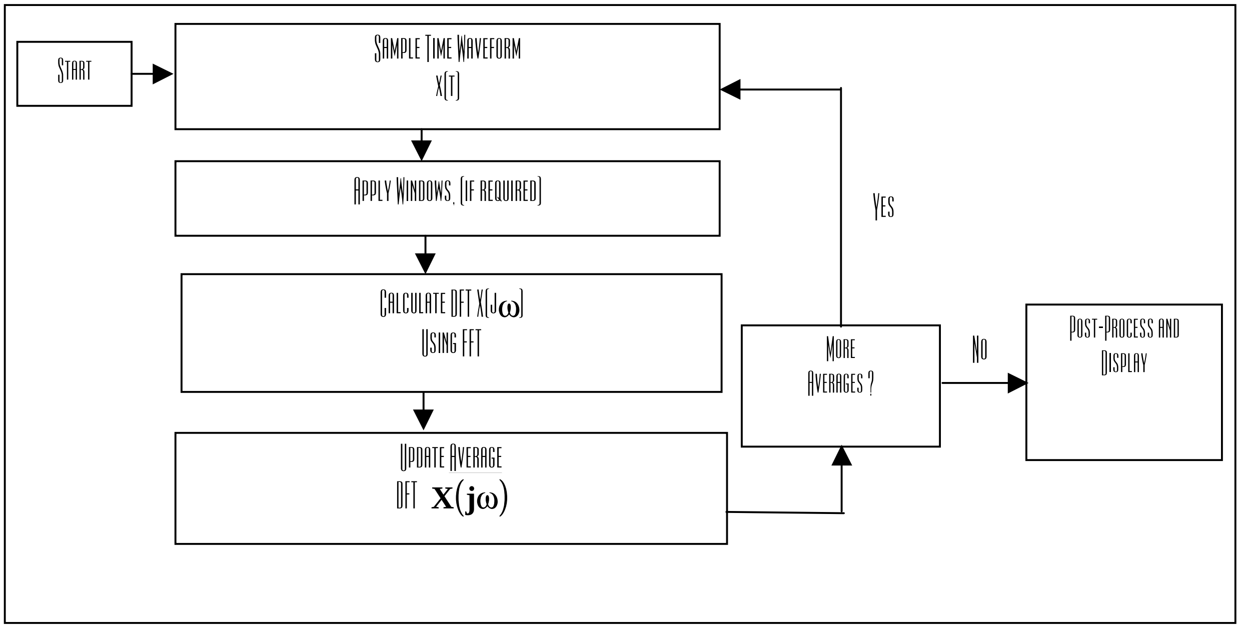

Figure 1

The Fourier Transform was calculated as,[3]

$$\mathbf{X(f)} = \int_{-\infty}^{\infty} \mathbf{x(t) e^{-j2\pi ft} dt} \qquad (1)$$

where: f = frequency in Hz
t = time in seconds

The Inverse Fourier Transform was calculated as,[3]

$$\mathbf{x(t)} = \int_{-\infty}^{\infty} \mathbf{X(f) e^{j2\pi ft} df} \qquad (2)$$

The Discrete Fourier Transform was calculated as,[3]

$$\mathbf{x(n\Delta t)} = \mathbf{\Delta f} \sum_{\mathbf{m=0}}^{\mathbf{N-1}} \mathbf{X(m\Delta f) e^{-j2\pi mn/N}} \qquad (3)$$

m = 0…, N-1

The Inverse Discrete Fourier Transform was calculated as,[3]

$$\mathbf{x(n\Delta t)} = \mathbf{\Delta f} \sum_{\mathbf{m=0}}^{\mathbf{N-1}} \mathbf{X(m\Delta f) e^{j2\pi mn/N}} \qquad (4)$$

n = 0…, N-1

Examination of the wide-band spectrum data indicated a high vibration occurring at 1x RPM of the motor (See Figure 2) and the fan (See Figure 3) shaft speeds on each fan.

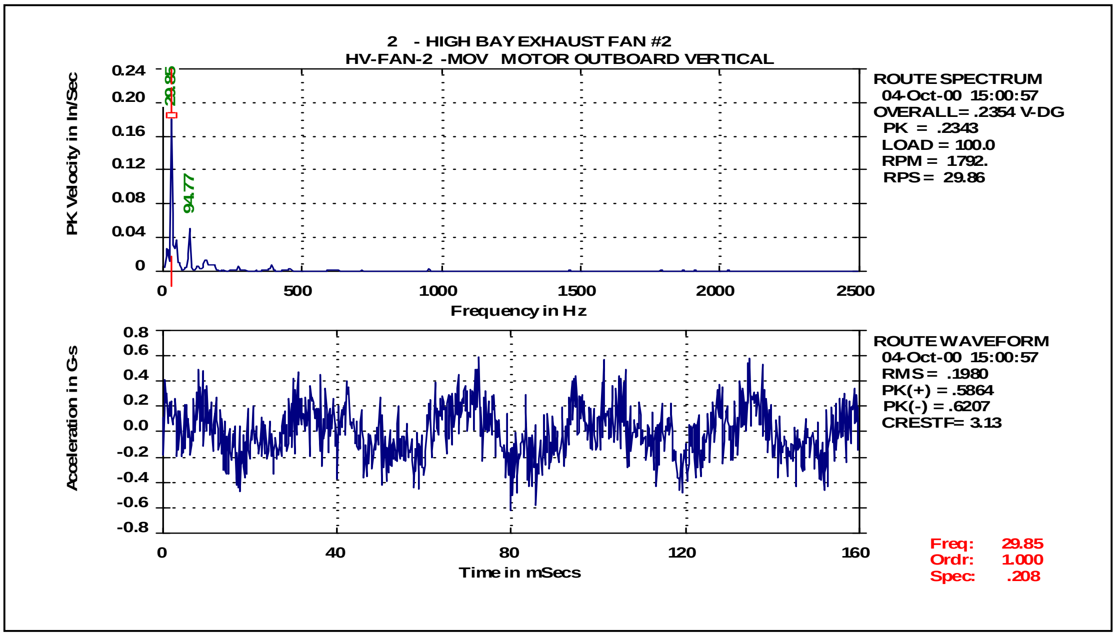

Figure 2

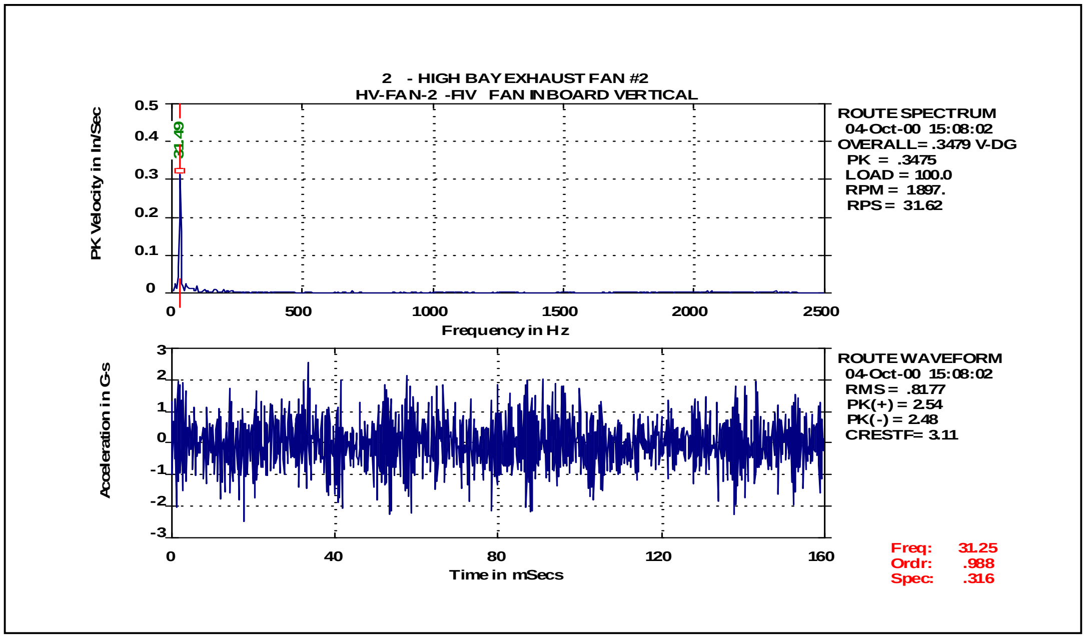

Figure 3

The analyst decided to perform zoom analysis at this time to see if there were two frequencies being shown as one frequency in the wide-band spectrum analysis.

Zoom Analysis

Zoom Analysis, a digital signal processing technique, enabled the analyst to collect a high-resolution spectral plot over a narrow frequency band. This signal processing took place in the FFT analyzer after the time waveform had been sampled. The analyzer utilized digital filtering that involved re-sampling, frequency shifting, and low pass filtering of sampled data to produce a high-resolution spectrum over a smaller frequency range.

The variables that determined the frequency range over which the analysis was performed using the CSI 2120 Machinery Analyzer were the Low Cutoff and Bandwidth settings. The Low Cutoff setting specified the desired low-frequency end of the spectrum and the Bandwidth setting specified the desired frequency above the Low Cutoff frequency setting.

Zoom analysis data was collected around the 1x RPM peak on each measurement point on the fan unit (See Figure 4 and 5). This data actually showed two frequencies instead of the single pulsating frequency seen in the wide-band spectral data. The difference between these two frequencies was the beat frequency.

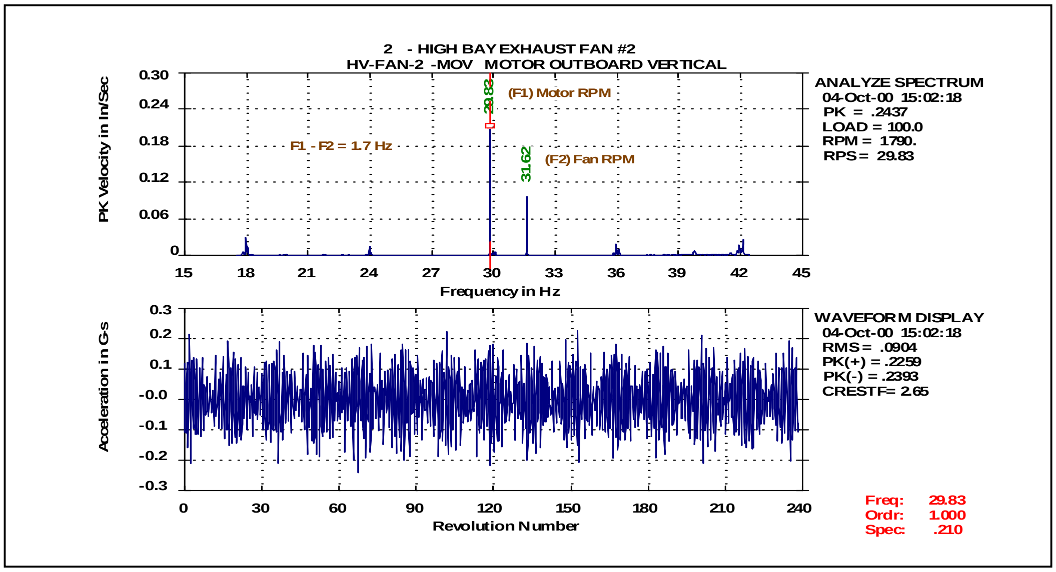

Figure 4

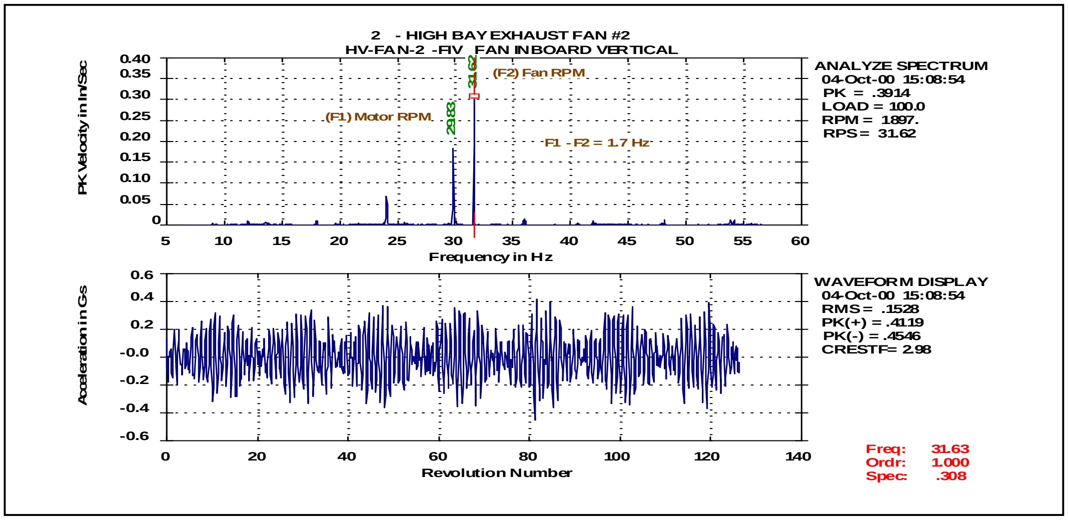

Figure 5

Maximum vibration will result in a beat frequency when the time waveform of one frequency comes into phase with the waveform of the other frequency. Minimum vibration occurs when waveforms of these two frequencies line up 180 degrees out of phase (See Figure 6).[1]

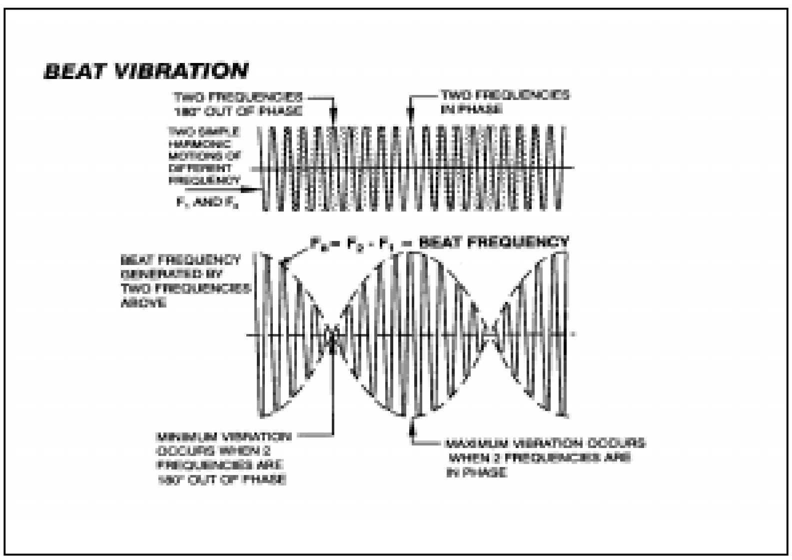

Figure 6

The Beat Frequency was calculated as,[1]

$$\mathbf{F_B} = \mathbf{F_1} - \mathbf{F_2} \qquad (5)$$

where: $\mathbf{F_B}$ = beat frequency
$\mathbf{F_1}$ = first frequency
$\mathbf{F_2}$ = second frequency

Conclusion

A review of the maintenance history for both fan units showed that maintenance had recently changed the belts on both units. It was also noted that during the start-up of the facility four years ago, both fan units were installed with adjustable speed sheaves.

Adjustable speed sheaves are frequently used during start-up of plant equipment to allow for the air balancing of the system. To adjust the air system the drive is stopped and the belt(s) are removed. The flanges must be unlocked and then adjusted to accommodate the desired speed increase or decrease. The flanges are then re-locked in their new position, belt(s) reinstalled, and belt(s) re-tensioned. The drive may then be restarted and the speed checked. This process can be repeated until the required speed is obtained.

During the last belt change, the belts on both units were removed and the sheaves were readjusted. This readjustment caused the speed of both fans to decrease 400 RPM, causing a beat frequency between the motor and fan to appear.

Recommendations

The recommendation was made and a work order issued to readjust both sets of adjustable speed sheaves to their normal settings. A new purchase order was prepared for two fixed sheaves to replace the existing adjustable sheaves. The fixed sheave recommendation was based on the review of operational data from the fans. During the four-year period since the start-up of the facility, no seasonal speed changes where required to maintain air balance on the system.

Upon completion of the work order the beat frequency between the motor and fan units disappeared and the vibration levels returned to normal.

References

[1] James E. Berry; Technical Associates of Charlotte, P.C.; "Level II Vibration Analysis Training Manual", Westinghouse Savannah River Company; January 6 – 9, 1998; Pages 6-186 & 6-187.

[2] Mark H. Richardson; Vibrant Technology, Inc.; "Structural Dynamics Measurements"; SD2000 – April 11 – 16, 1999.

[3] Mark H. Richardson "Fundamentals of the Discrete Fourier Transform", Sound & Vibration Magazine, (March, 1978).